Modelling calving of Greenland Outlet Glaciers in Elmer FEM

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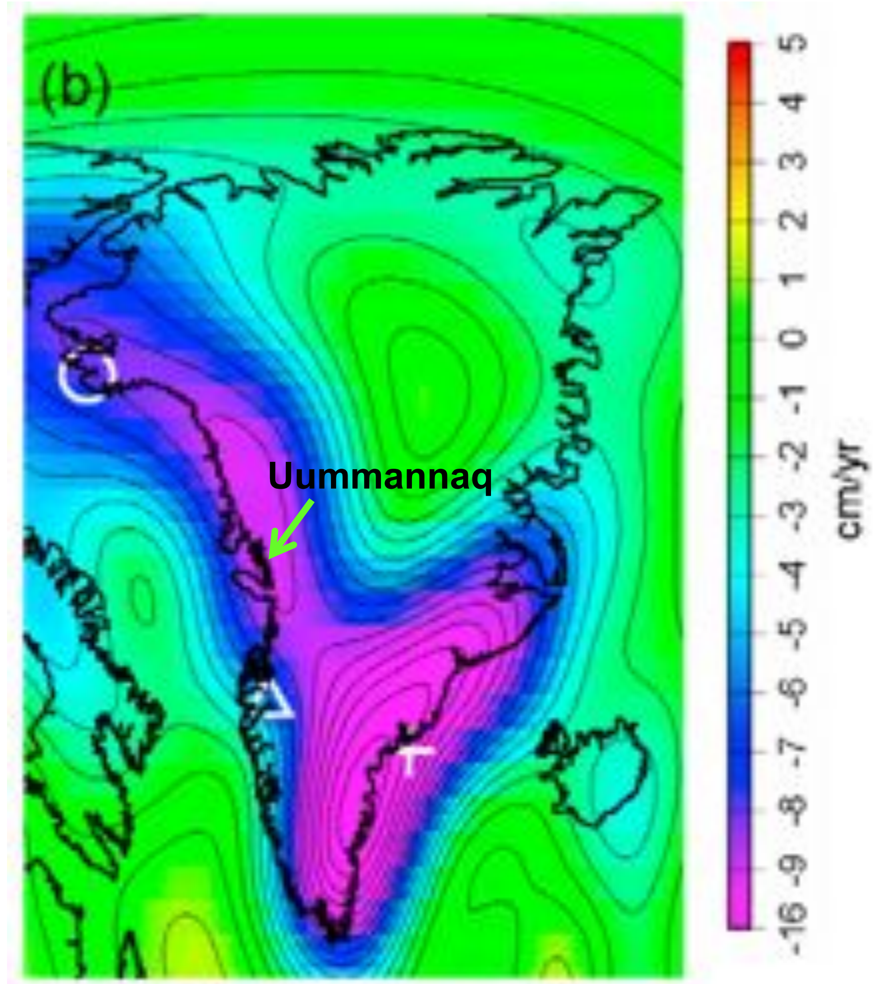
Why model calving?

- Important mass balance term for GIS
- Insufficiently understood for confident prediction
- Recent data suggests sensitivity to ocean and/or atmospheric climate change
- How might these changes influence long-term outlet glacier stability?



Mass loss as measured by the GRACE satellites.
Source: Khan et al. (2010)

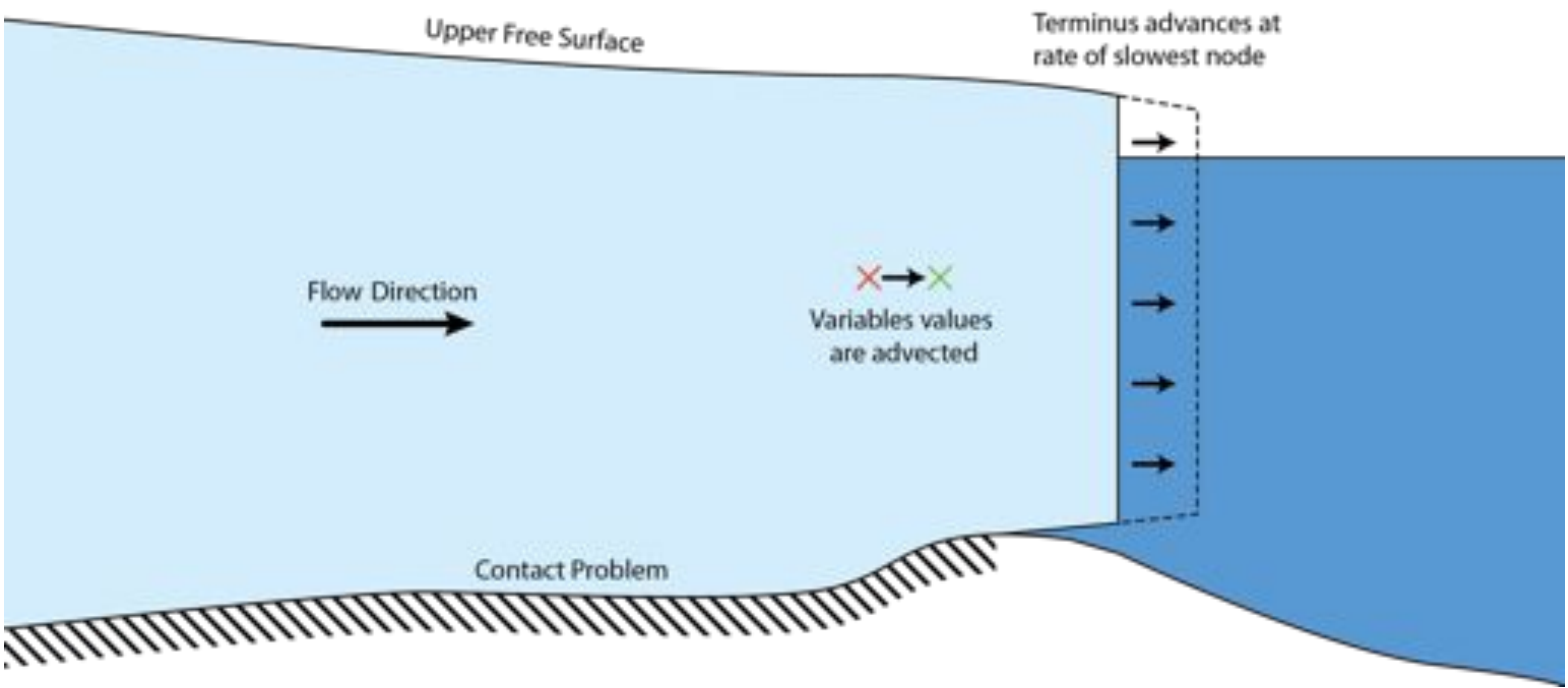
How to model calving

Requirements:

- 3rd moving boundary
- Two instances of Mesh Update
  - Advance
  - Retreat
- Calving criterion
  - when and where does calving occur?
- Interpolation routines

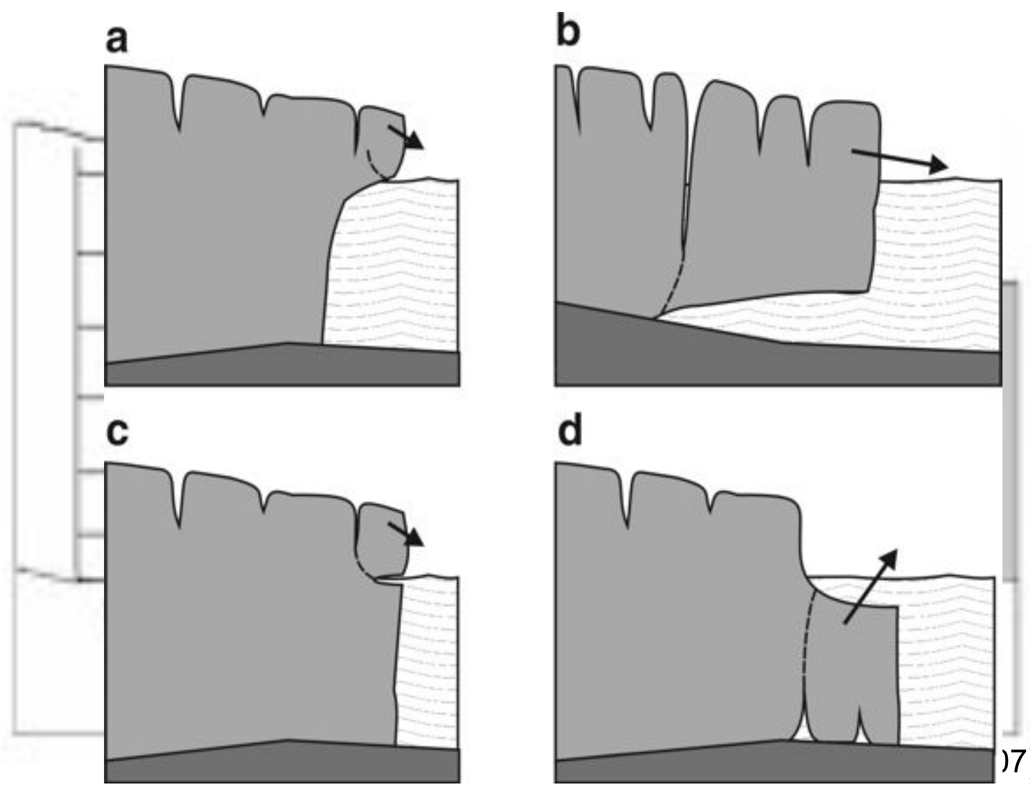
Advance

- Mesh displacement = Physical displacement
- Field variables are advected
- Use Arbitrary Lagrangian-Eulerian (ALE) formulation for free surfaces
- Frontal melting can be incorporated here



Predicting Calving

- Variety of related processes
- Occurs when a fracture penetrates the ice thickness
- Assisted by hydrofracturing when sea-water enters crevasses
- Thus, calving is predicted to occur when crevasses reach sea-level (Benn et al., 2007)
- Simple first-order approximation, but physically based.



Source: Van der Veen (2002)

Parameterising Crevasse Depth

<u>Force Balance Approach:</u>

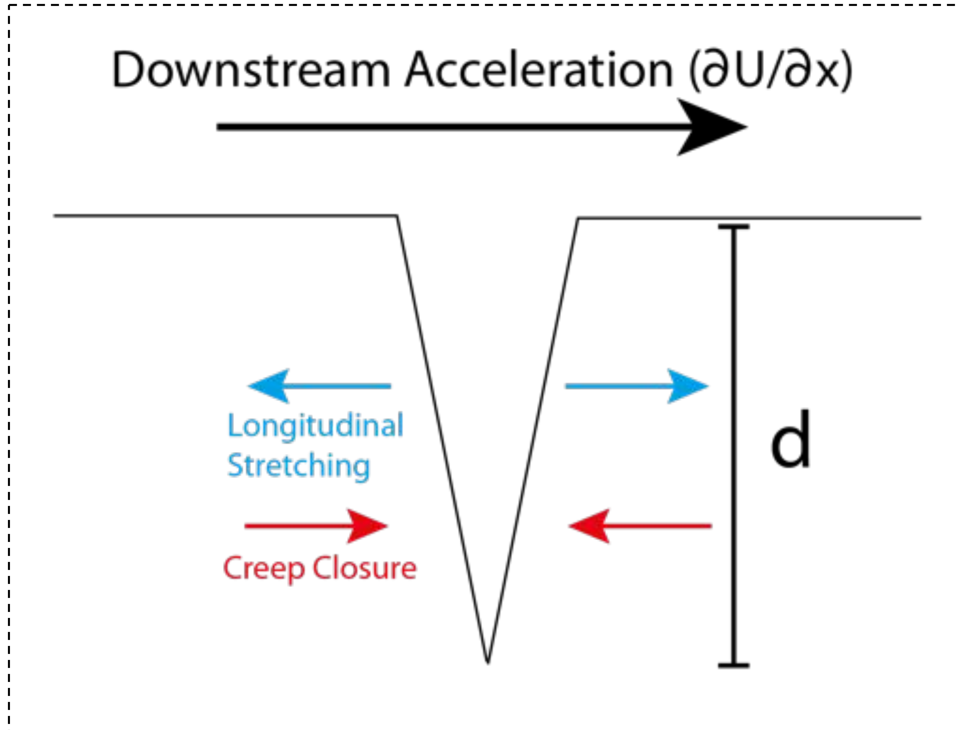
At tip of crevasse, forces are balanced

Creep closure = $dg\rho_i/2$

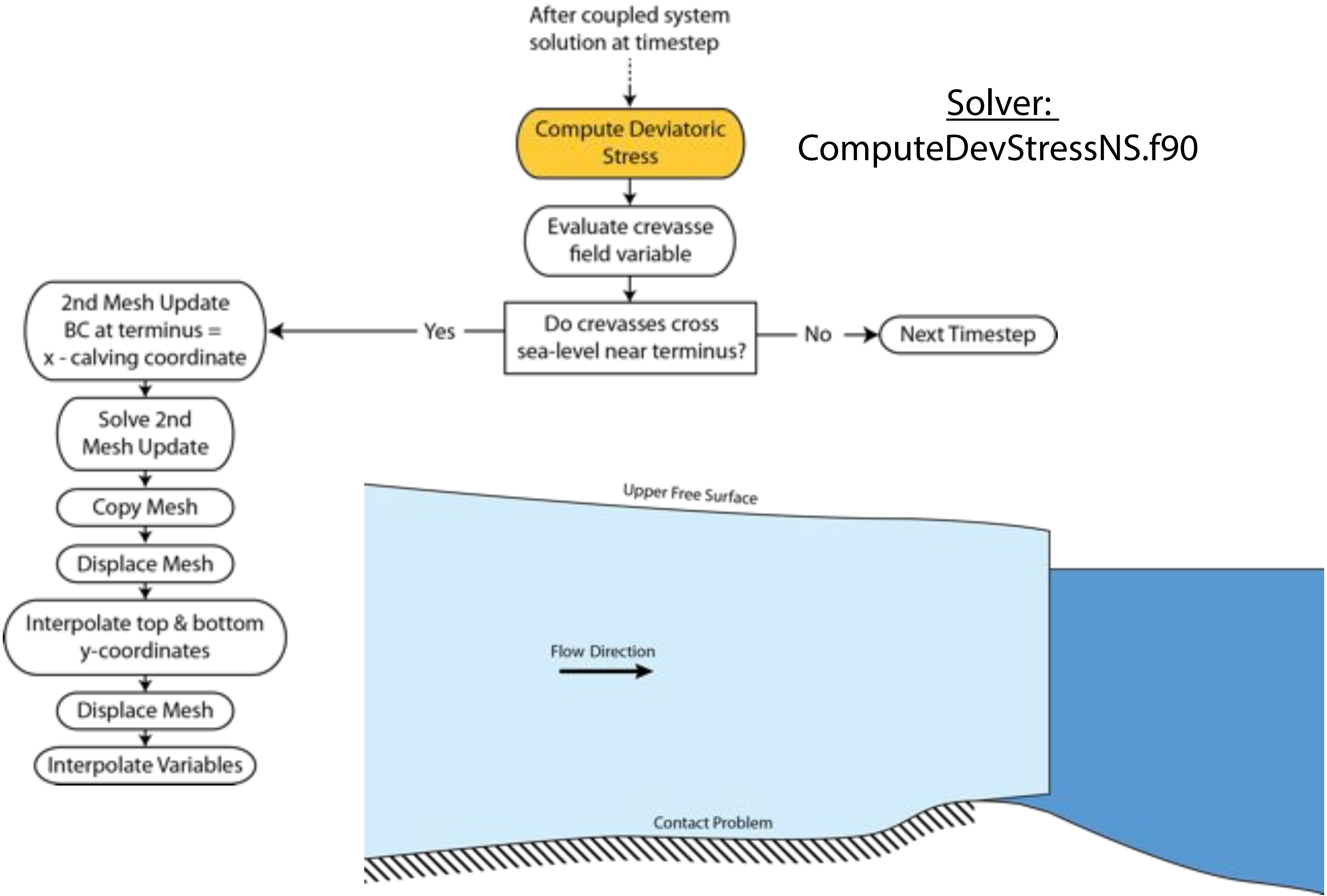
Long. Dev. Stress = σ'_{xx} = $(\partial U/\partial x/A)^{1/n}$

Define a field variable 'C', positive where crevasse exists:

$$C = (\partial U/\partial x/A)^{1/n} - dg\rho_i/2$$

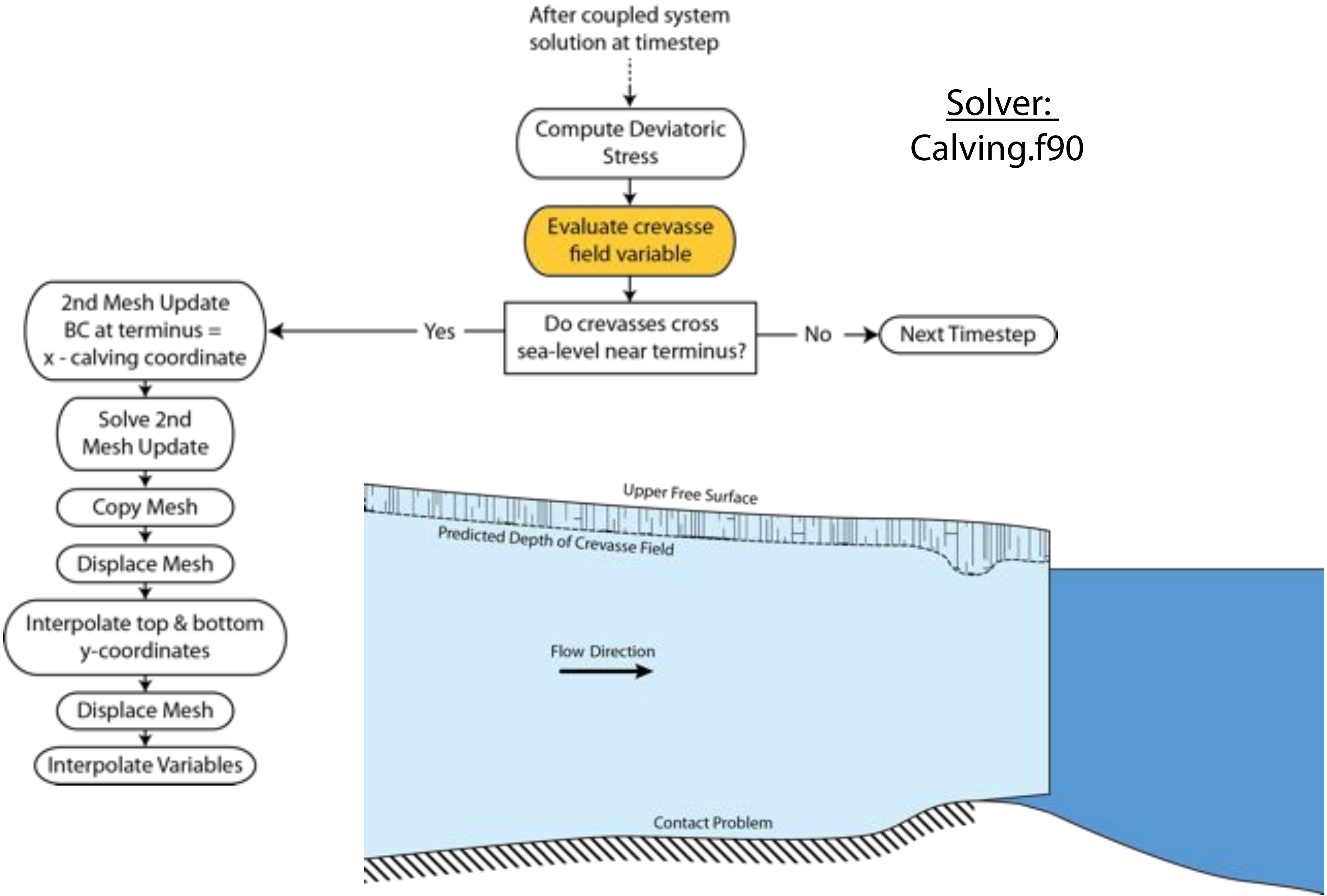


Calving Implementation



Solver:
ComputeDevStressNS.f90

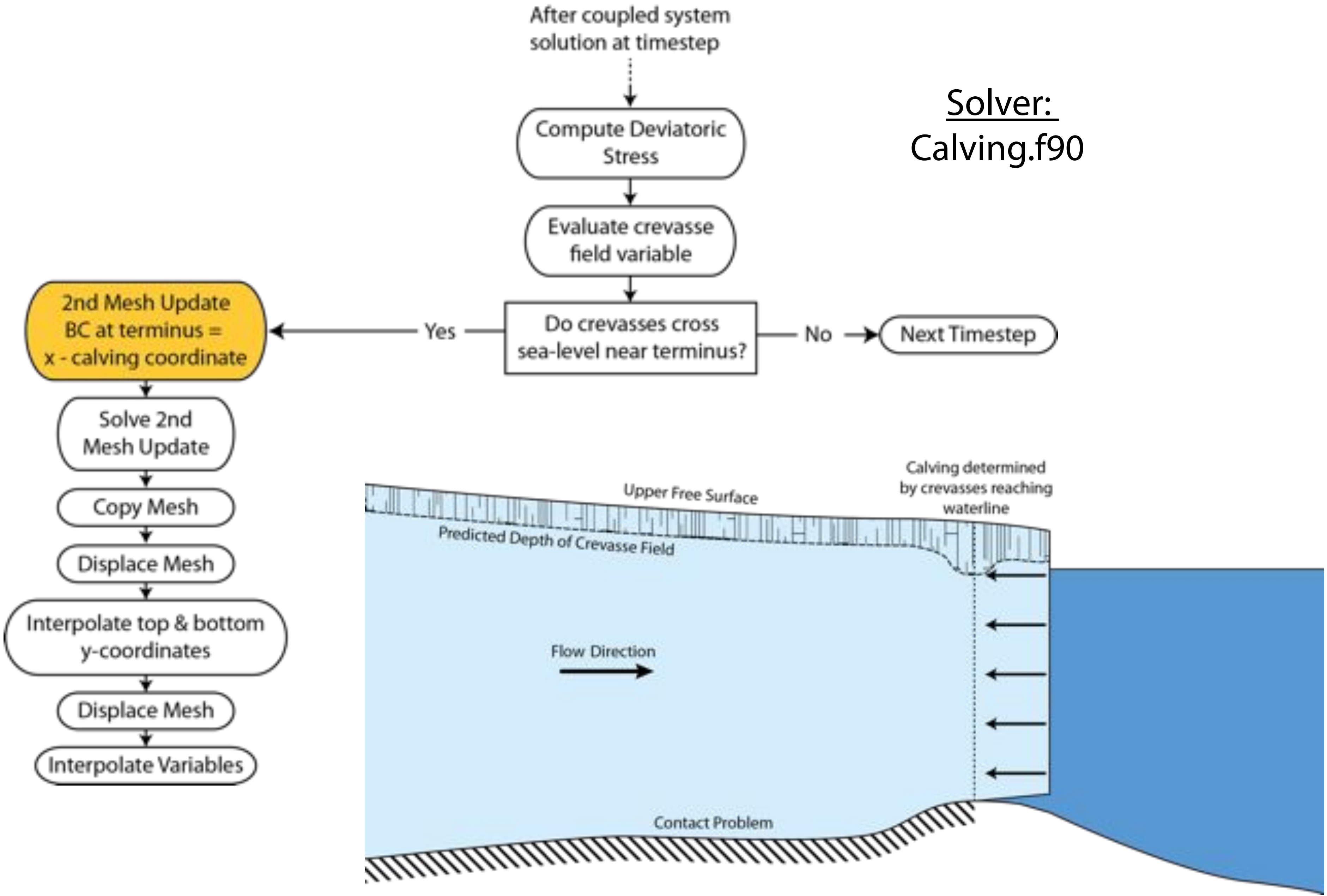
Calving Implementation



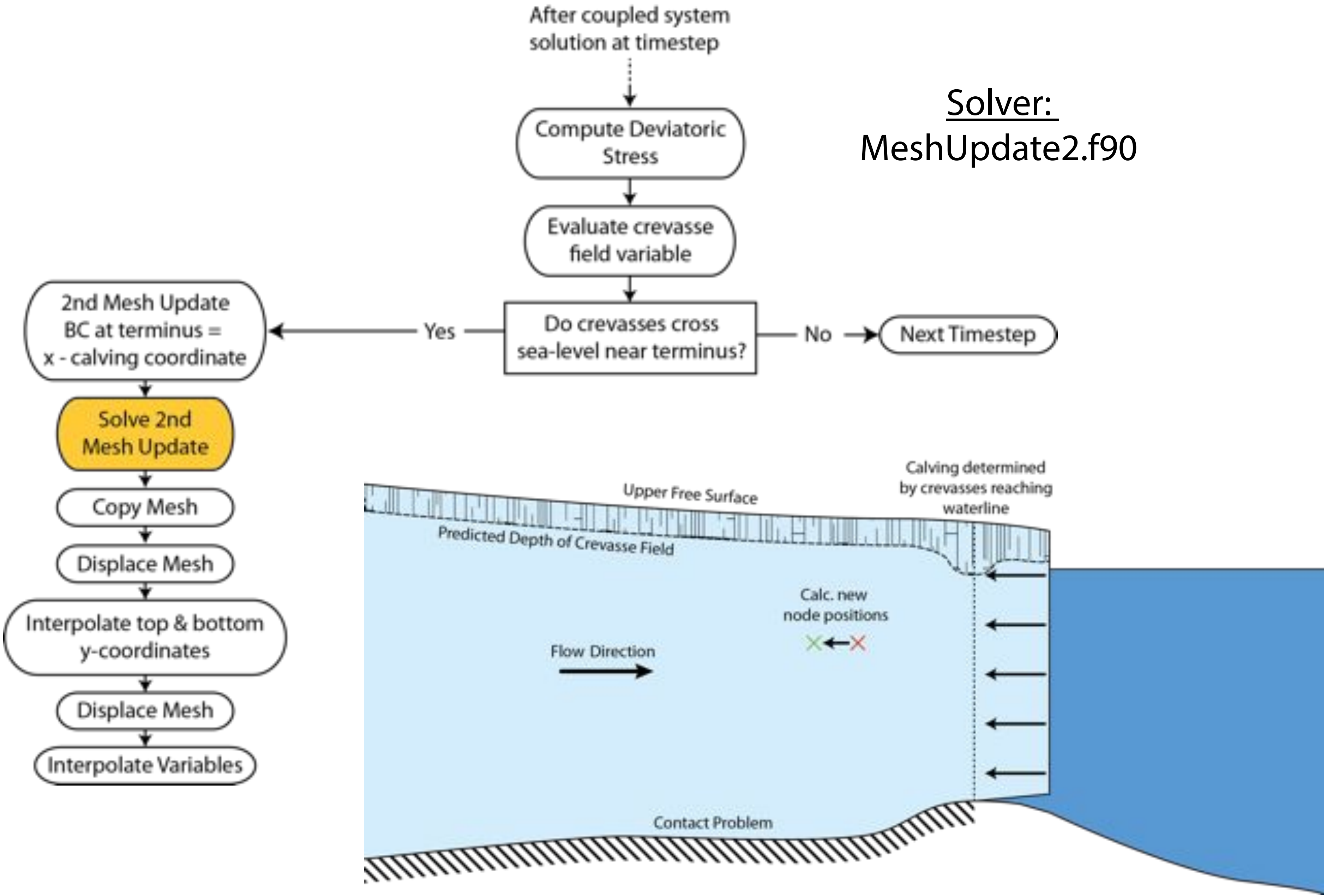
Solver:
Calving.f90

Calving Implementation

<u>Solver:</u>
Calving.f90



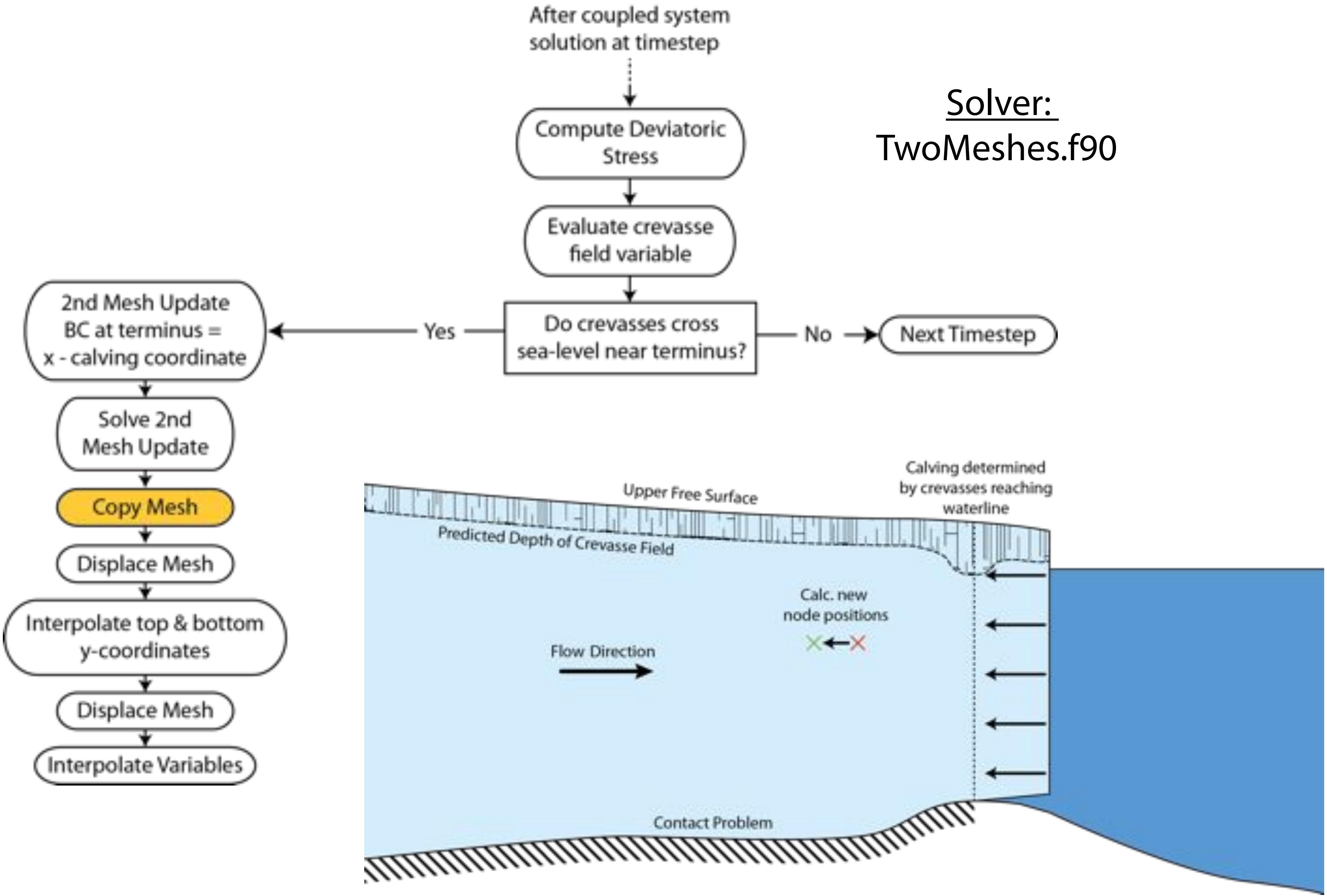
Calving Implementation



<u>Solver:</u>
MeshUpdate2.f90

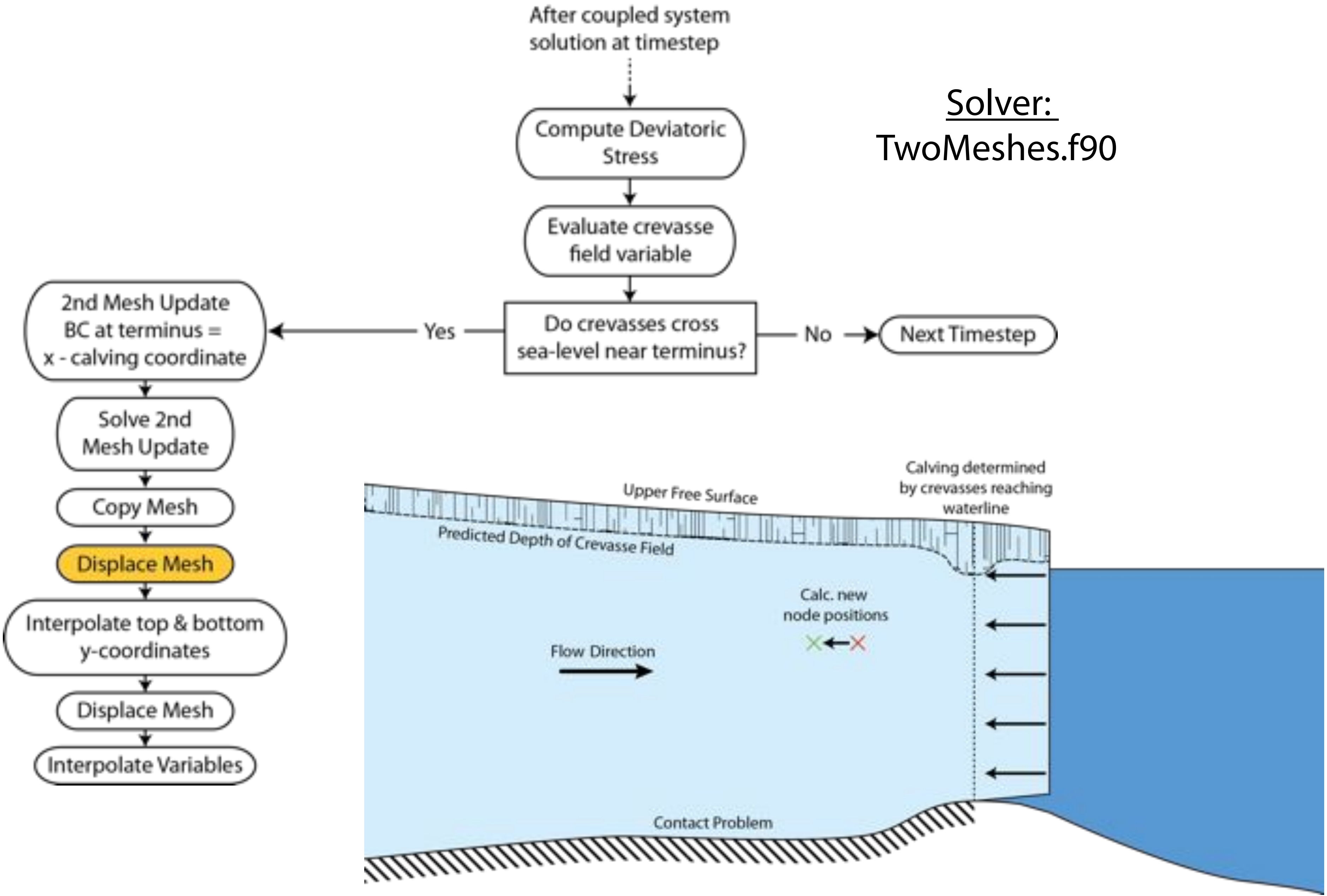
Calving Implementation

<u>Solver:</u>
TwoMeshes.f90

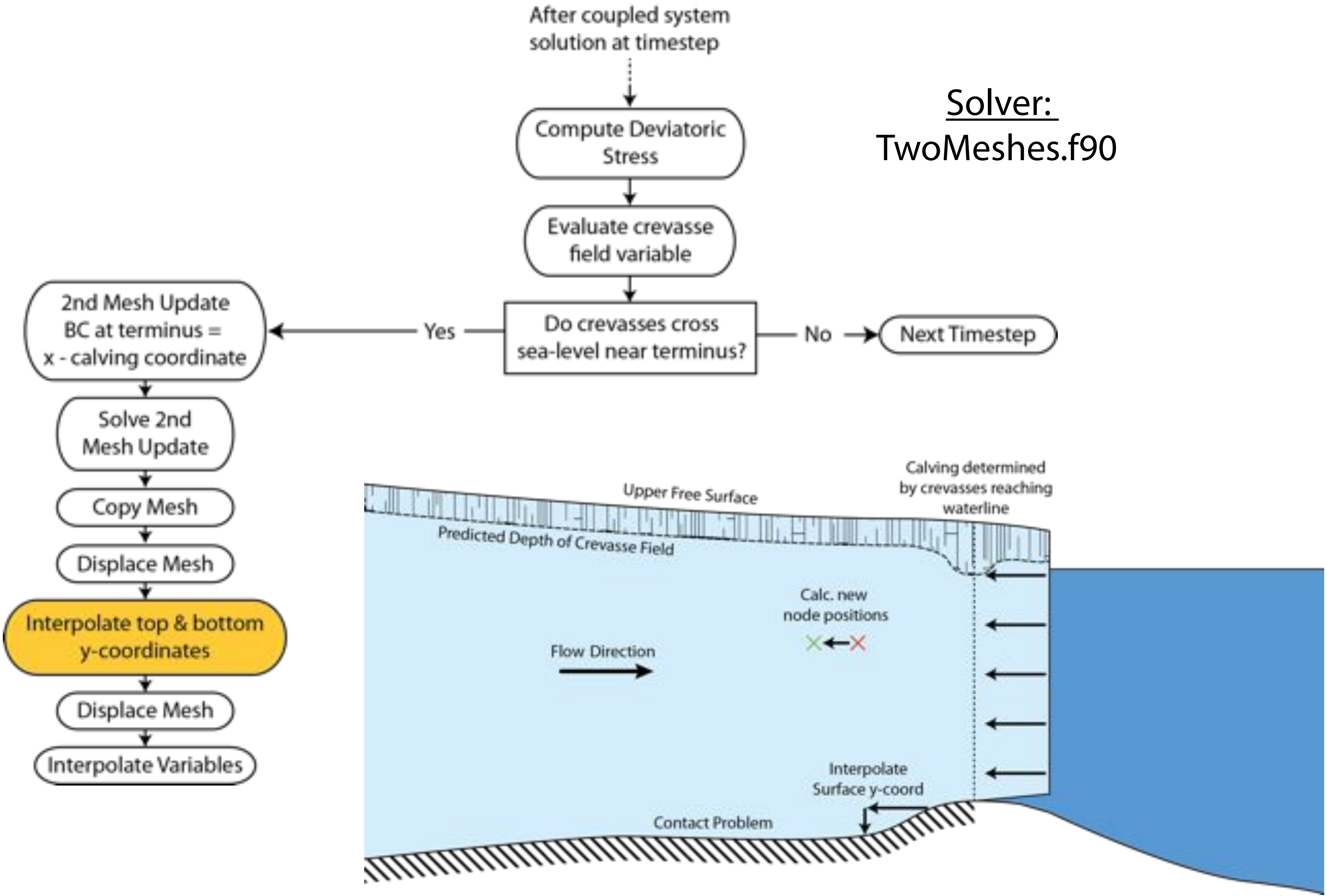


Calving Implementation

<u>Solver:</u>
TwoMeshes.f90



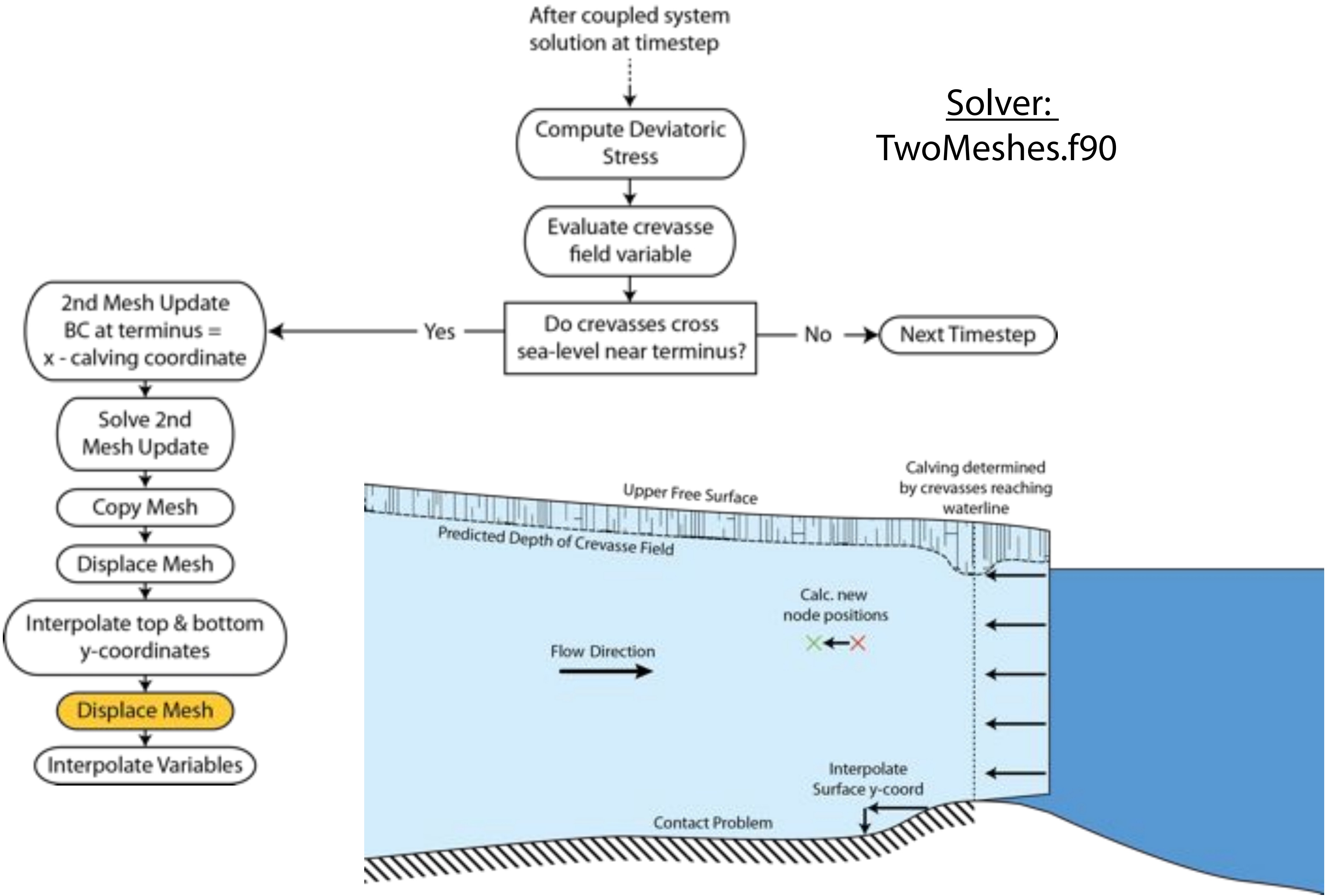
Calving Implementation



Solver:
TwoMeshes.f90

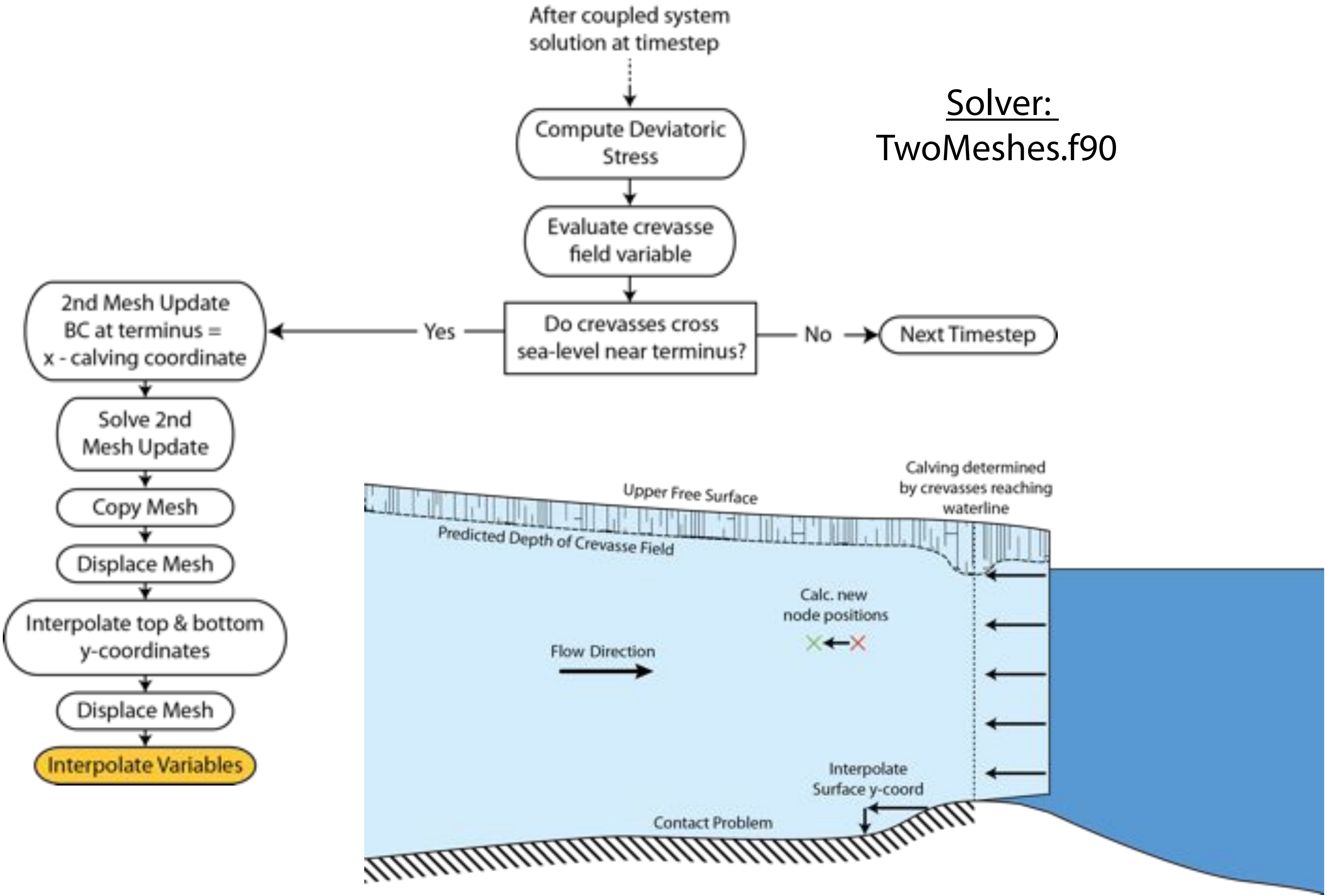
Calving Implementation

Solver:
TwoMeshes.f90



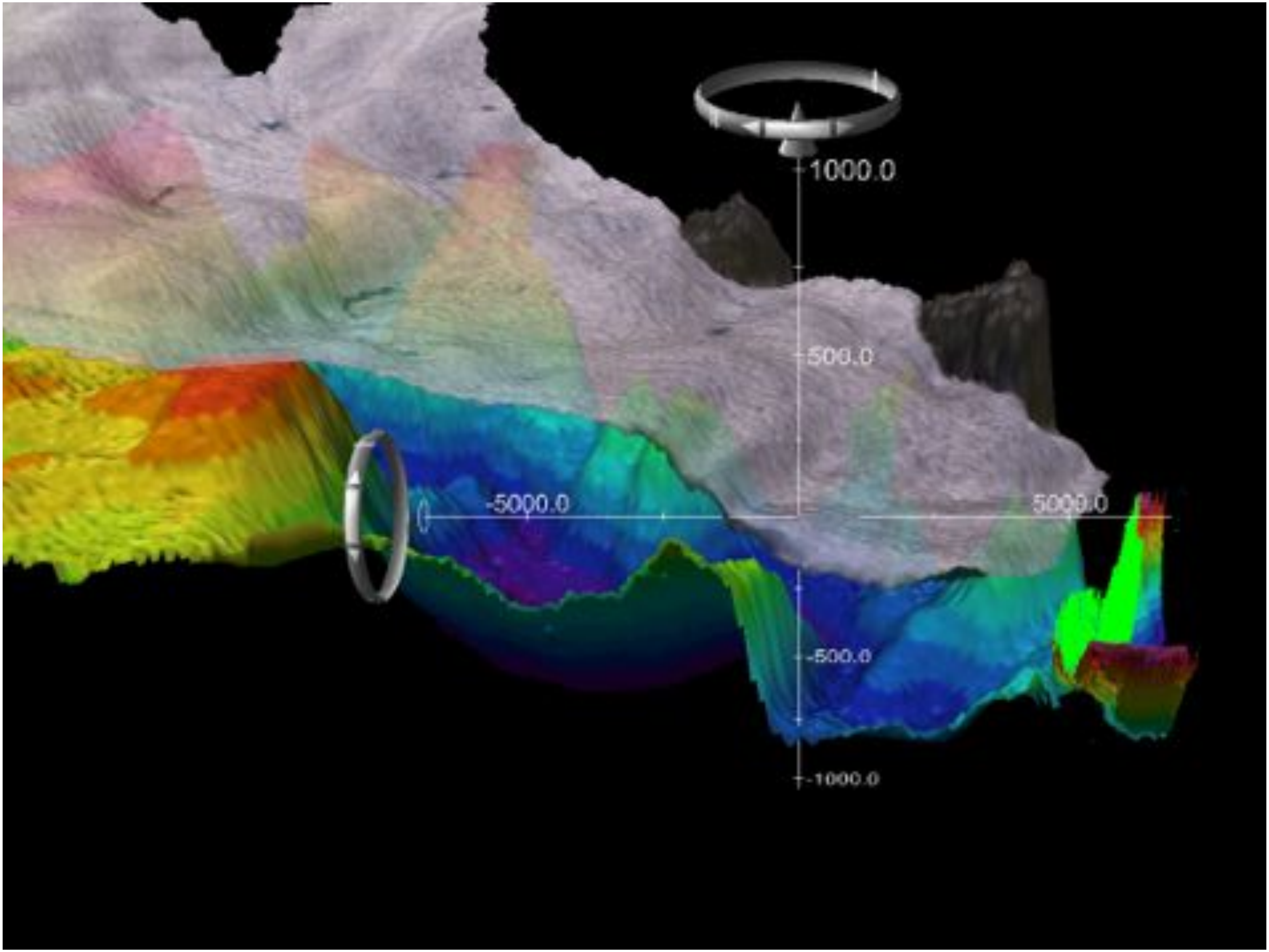
Calving Implementation

<u>Solver:</u>
TwoMeshes.f90



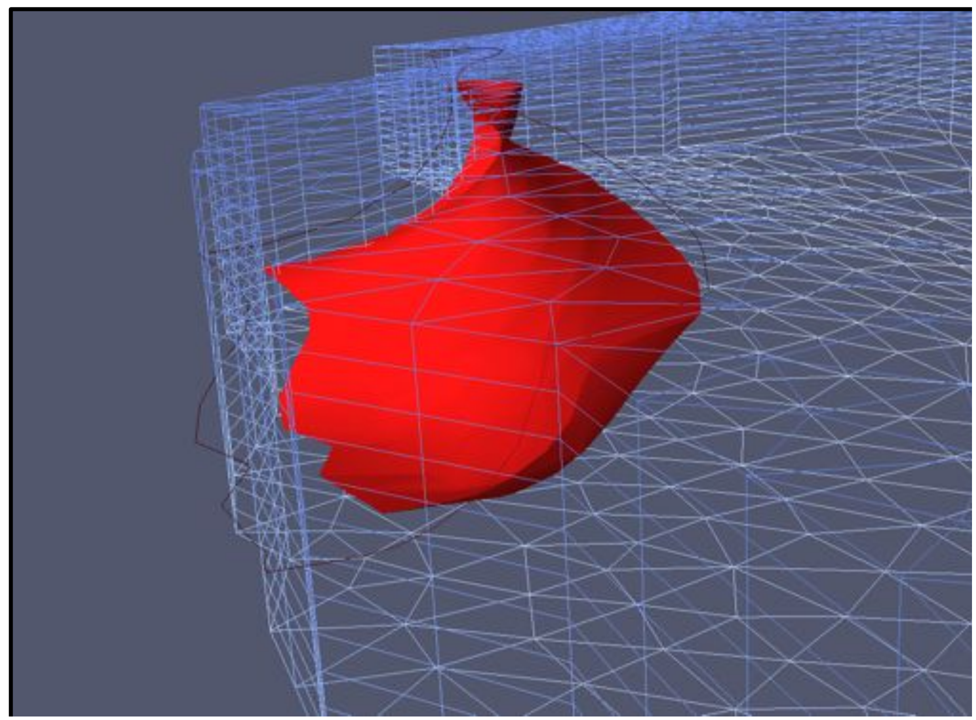
Moving to 3D

- New data for Store:
  - Improved bed data
  - High-res frontal point cloud


1000.0
500.0
-5000.0
5000.0
-500.0
-1000.0

Moving to 3D

- New data for Store:
  - Improved bed data
  - High-res frontal point cloud
- Challenges:
  - Line becomes surface
  - Mesh update more complicated
  - Include more stress terms?
  - Non vertical boundaries?



Thanks for listening!